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Application of Computer Generated Color Graphic Techniques to the Processing and Display of Three Dimensional Fluid Dynamic Data



Bernard H. Anderson, C. W. Putt, and C. C. Giamati
Lewis Research Center
Cleveland, Ohio

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NASA

APPLICATION OF COMPUTER GENERATED COLOR GRAPHIC TECHNIQUES TO THE PROCESSING AND DISPLAY OF THREE DIMENSIONAL FLUID DYNAMIC DATA

by Bernhard H. Anderson,* C. W. Putt,† and C. C. Giamati†

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

ABSTRACT

As part of an overall effort to support the NASA Energy Efficient Engine Program, a three part effort was conducted to investigate the primary mechanisms controlling the mixing process within modern turbofan mixer nozzles. This effort included (1) an experimental investigation (2) an analytical study and (3) a color graphic technique development program. The color graphic techniques were developed for two different underlying reasons (1) to reconstruct the measured flow field from low resolution experimental data to give more physical meaning to this information and (2) to scan and interpret the large volume of computer generated data from the three dimensional viscous computer code used in the analysis study. Color coding techniques developed for the processing of remote sensing imagery were adapted and applied to the representation of three dimensional fluid dynamic experimental and analytical data. Animated movie sequences were also made by using these color coding techniques which allowed the researcher to study the dynamic nature of the mixer nozzle flow field. This animation resulted in a higher awareness of the dynamic aspects of the fluid mechanics of mixer nozzles and an improved understanding of the processes involved.

INTRODUCTION

As part of an overall effort to support the NASA Energy Efficient Engine program[1-3] an experimental and analytical effort was conducted to categorize and evaluate the primary mechanisms controlling the mixing process within modern turbofan mixer nozzles. Results of this investigation have been published,[4-8] which clearly emphasize the importance of the lobe exit plane secondary flow field and vorticity signatures.

Because of the large volume of experimental and analytical information involved, it became apparent that better graphical methods had to be developed to (1) scan and interpret the large volume of computer generated data from a three-dimensional viscous analysis, and (2) reconstruct the flow field from limited experimental data to give more physical meaning to this information. The role of the various aerodynamic phenomena could not easily be understood using the standard graphical techniques. Therefore, it was decided to adapt the color coding techniques used in processing remote sensing imagery and apply them to the mixer nozzle flow field. In order to better understand the dynamic nature of these processes, these color coding techniques were used to make animated movie sequences from both the experimental and analytical data. This allowed the viewer to easily track these processes as they were convected through the mixer nozzle and to better understand their dynamic significance.

This paper gives a brief review of both the experimental and analytical effort and describes how these color coding techniques were applied to the data from each of these sources.

MIXER NOZZLE FLOW FIELD

The mixer nozzle flow field was constructed from two sources of information; (1) an experimental investigation where limited total temperature and pressure data were obtained in the cross section and (2) a three dimensional viscous analysis which generated large quantities of flow field data. Data from both sources of information had to be processed and displayed using color display techniques for different reasons. It was very important to computer enhance the experimental data to "fill in" where measurements were not obtained in order to complete the flow field picture. The analysis, however, produced too much information to be reasonably understood. Therefore this also had to be processed and displayed using color techniques.

Experimental Apparatus

The test apparatus used has been described in a previous paper[6] and consisted of two basic parts: a fixed upstream model section and a rotating shroud, Fig. 1. The upstream section simulated the flow path through a typical high by-pass turbofan engine. A cross-section of the model is shown in Fig. 2. Heated air was supplied to the core passage and flowed through the lobe section. Unheated air was supplied to the fan passage and flowed around the lobe section which was interchangeable. In this paper, only the results obtained with one lobe geometry are presented and this configuration had a penetration (lobe tip radius/shroud radius) of 0.822 and the circumferential spacing ratio (core lobe included angle/fan lobe included angle) of 0.5. The ratio of the shroud length to the inside shroud diameter (at the lobe exit plane) was 0.71.

Total pressure and temperature measurements were made upstream in both the fan and core flows. Instrumentation rakes were also mounted in the rotating shroud for probing the mixer flow field (see Fig. 2). Total temperature rakes were located at five axial stations in the mixing region. The first station was at the lobe exit plane, the second was halfway to the end of the plug, the third was at the end of the plug, the fourth was midway between the plug end and the nozzle exit, and the fifth station was at the nozzle exit plane. The rakes at the lobe and nozzle exit stations as well as the rotating mechanism are shown in Fig. 1. Total pressures were also measured at the lobe and nozzle exit stations. The temperature data were obtained over a 54 degree segment in 3 degree increments at 14 radial positions.

*Head, Aerodynamics Analysis Section.
†Aerospace engineer.

Analysis

The three dimensional viscous analysis used in this investigation is described in previouis papers[9],[10] and represents a three dimensional finite difference solution to the parabolic Navier Stoke equations. The mesh used in these calculations as well as the mixer geometry under study are shown in Fig. 3. The area immediately downstream of the nozzle plug tip was faired in with an assumed streamline to model the expected separated flow region in this mixer nozzle. The curvilinear coordinate system shown in Fig. 3 was constructed to fit the flow passage boundaries and has 21 streamwise radial points and 40 radial nodes. In planes of constant azimuth, orthogonal streamlines and velocity potential lines were constructed from a two-dimensional plane incompressible analysis. The x-y coordinate system was then rotated about the mixer axis to form the axisymmetric coordinate system.. Five reference stations are identified on Fig. 3 and these correspond to the 5 experimental survey stations. These are labeled 1, 8, 13, 17 and 21 and correspond to the computational nodal stations nearest to the probe locations: Station Number 1 corresponds to the lobe exit survey station while station Number 21 is the mixer exit station.

Although the mixer geometry is axisymmetric, the flow is three dimensional due to the azimuthal variation of the hot and cold streams. However, due to observed symmetry, only a 1/2 lobed pie-shaped segment of the transverse coordinate surface was considered. The shape of this segment and the extent of typical hot and cold streams at the lobe exit station is shown in Fig. 4. A comparison between the computational and experimental cross sectional lobe shape are also shown in Fig. 4.

Secondary Flow Field

The central problem in this program was to understand the behavior of secondary flows in turbofan forced mixer nozzles. It is very difficult to obtain detailed measurements of secondary flows which originate in the lobe section and are convected downstream through the mixer nozzle. It is the structure of these secondary flows which determine mixer nozzle performance. Total temperature, however, is convected along streamlines and is easier to measure. The temperatures that were measured with the rotating rake resulted directly from the secondary flows existing in the mixer passage. Therefore, if reasonable agreement between measured and calculated temperatures are achieved, it is safe to assume that the secondary flows themselves are in reasonable agreement.

The mixer nozzle secondary flow field was calculated using a fully viscous three dimensional analysis and the results are presented in figure 5. Although the computational segment included only one half a fan segment and one half a core segment, the computational results in Fig. 5 were reflected to include two core segments and two fan segments. The secondary velocities presented are normal to the streamwise mesh coordinate. The inflow secondary velocity field shows a very strong vortex pattern aligned with the interface between the core and fan streams. At station number 8, which is located halfway along the plug surface, the vortex pattern has condensed into a more circular configuration. This vortex pattern moves radially outward as can be observed in Figs. 5(c) to (e). The original vortex is still very dominant as it exits from the mixer nozzle, Fig. 5(e). Variations in this secondary flow vortex pattern, cause changes in mixer nozzle performance.

COLOR IMAGE PROCESSING TECHNIQUES

Color coding techniques used in processing remote sensing imagery proved to be a highly effective means to display and enhance the limited total temperature data obtained in the experiments and the large volume of data obtained from the three dimensional viscous analysis. Both color stills and movie sequences were produced to illustrate the various aerodynamic processes that take place within mixer nozzles.

Image Processor

The mini-computer based color film recording and color CRT display system[11] used at Lewis Research Center for processing remote sensing imagery and fluid dynamic data is shown in Fig. 6. The system includes a PDP 11/34 mini computer with main memory, several removable disk cartridges to contain system software and applications programs, magnetic tape units to read and write tapes, and a keyboard console for input of user commands. The image output hardware, dicomed film recorder and CRT color monitor contain limited memory and processor capability that can accept both data and command words from the mini-computer. The CRT color monitor is divided into a matrix consisting of 512 lines with 512 addressable positions per line. These addressable locations are called pixcells and each pixcell can be assigned a color made up of any combination of 16 shades of red, green and blue.

A simple but flexible software interface was developed for transferring information from the host computer at Lewis to the PDP11/34 interface and to the Grinnel display memory. To create a CRT image, the following steps are necessary.

At a location called the input buffer, a record is read from magnetic tape into the mini-computer memory, with a format corresponding to a scan line of pixels from the original scene. The data in the input buffer is reformated and stored along with suitable commands in another mini-computer memory location designated as the output buffer for eventual transfer to the CRT color monitor display unit. These activities occur under control of the mini-computer CPU, which finally initiates a transfer of the output buffer contents to the display processor. The net result is that a scan line of up to 512 pixels are stored in the Grinnel display memory. Repetition of this process can store up to 512 scan lines, usually in a one-to-one correspondence with the records on the magnetic tape. The display memory locations in turn are in a one-to-one correspondence with a square array of locations on the CRT screen, so one can consider the CRT screen image to be made up of 512x512 colored dots or pixels. The display processor contains electronics which continuously reads the contents of the display memory and generates a T.V. raster with appropriate red, green, and blue signals for the color CRT (a standard commercial T.V. monitor). The screen is refreshed 30 times per second which is much faster than an image can be read into the entire display memory (about 10-15 sec). Color movies were made by reading a frame of information from the magnetic tape into the Grinell display memory. The movie camera was triggered electronically by the PDP 11/34 to take four successive pictures of the TV color monitor. The process is repeated for each frame of information to produce the animated sequence.

Scan Line Techniques

Scan line graphical techniques were developed to construct a 256x256 pixcell matrix from the lower resolution data array generated by the rotating total temperature rake in the experiment and the array of com-

puted results from the three dimensional viscous computer code . Even though the Lewis image processor has a 512x512 pixcell resolution, a 256x256 pixcell matrix was used to reduce the amount of information processed and stored. This was accomplished by clustering four pixcells together.

Scan line graphical techniques[12] developed for hidden line and hidden surface removal algroithms proved useful in interpolating across any general computational mesh to fill in the pixcell matrix. Figure (7) illustrates the nature of the interpolation problem encountered using color raster display techniques. A flow field variable such as total temperature is known at each grid node. However, the interpolation must take place along a scan line associated with the pixcells and not along the grid lines because that is how the information is stored and processed in the image processor. Thus the problem requires a change in coordinate system and an interpolation process to obtain proper information for the 256x256 image matrix and store it along scan lines which read from left to right.

Color Image Signature

The color image formed by the Lewis Image Processor from the 256x256 pixcell information matrix is called a signature and represents a natural color contouring technique. Figure 8 shows a comparison between the color image signature and the standard contour representation for the total pressure measured at the lobe exit, station number 1. The black and white contour representation Fig. 8(b) is a mirror image of the signature on Fig. 8(a). To obtain the signature in Fig. 8(a), the total pressure was color coded with light blue representing a total pressure ratio of 0.88 and yellow a pressure ratio of 1.0. All the colors and shades of color from blue to yellow represent increasing total pressure. Figure 8 illustrates the difficulty in conveying physical meaning to experimental data using contour representations with their corresponding contour values. The lower energy region in the bottom of the fan trough is almost completely lost due to the observer having to associate the letter labels on the contour plots with the numerical contour values tabulated in Fig. 8(b). This association is much easier for the observer viewing the color signature in Fig. 8(a), principally because a color code is simpler to remember. The nonsymmetric loss region associated with a strut well upstream of the lobe section is vividly retained in the color signature but almost completely lost in the contour representation. The low resolution definition of the contour plots of Fig. 8(b) is associated with the limited experimental data obtained with the total pressure rake. However, the color image signature appeared to improve the low resolution problem.

Figure 9 presents a comparison between the color image signature and standard contour representation for total temperature ratio at station number (8), which is about halfway down the plug. The total temperature ratio in Fig. 9(a) was color coded so that light blue represents the fan temperature ratio of 0.740 and the light yellow is the core temperature ratio of 1.00. All the colors and shades of color between blue to yellow represent increasing total temperature. Again, physical insight into the significance of the contour plots is lost in Fig. 9(b) due to the difficulty in associating a lettered contour label with a temperature value. However, great physical meaning is given to the color image signatures because of the natural color association which exists between the yellow or hot core flow and the cooler blue fan flow representation. In the still and movie sequence to follow, the experimental signatures were obtained by cutting out a 30 degree segment of data between two fan trough centerlines and reflecting this region to give a 60 degree image segment. This was found necessary because the experimental data survey did not always include two complete core and fan regions.

Figure 10 presents a comparison between the total temperature signature obtained on the image processor for both the experiment and analysis at five experimental survey stations identified in Figs. (2) and (3). The total temperature ratio was coded using the same color bar used in Fig. 9(a), i.e. light blue representing the fan temperature ratio of 0.740 and yellow the core temperature ratio of 1.0. In general, the analysis simulated the basic flow physics as indicated by the total temperature measurements represented by the color signatures in Fig. 10. At station 21, the mixer exit, the characteristic horseshoe vortex was predicted by the analysis, Fig. 10(e). From this still sequence, it appears that there is greater activity in the forward region, which includes the plug, than the reward region downstream of the plug.

A computer animated color movie was created to study the dynamic nature of the mixer nozzle flow field as represented by the rate of change of the total temperature signature through the mixer passage. The changes in total temperature signature from the lobe exit, Fig. 10(a) to the mixer exit, Fig. 10(e), were brought about primarily by the action of secondary flows generated in the lobe section and convected downstream through the mixer passage. In the movie sequence, it readily became apparent that these secondary flows tended to be reinforced by the normal static pressure gradient created by the plug and attenuated downstream of the plug region by the action of viscous forces. This dynamic effect which depends on the balance pressure and viscous forces could also have been concluded by examining the average vorticity distribution through the mixer passage that was calculated in the analysis. In general, the analysis was able to reasonably model the dynamic effects that the experimental data suggested. In addition, the movie sequence heightened our awarness of the fact that the type of flow field under study was indeed dynamic and that the analysis modeled the rate at which the various interactions were taking place through the nozzle. It is very doubtful that these same conclusions could have been reached simply by an examination of the total temperature signatures presented in Fig. 10.

Other examples of the uses of the Lewis Color Image Processor to problems associated with the turbofan mixer nozzle program are presented in Figs. 11 and 12. Figure 11 illustrates the effect of inflow conditions on the total temperature signatures at the mixer exit. The ideal inflow case was used as a baseline calculation and it represents a condition under which no secondary flow is introduced into the mixer passage. This color representation was particularly useful because it allowed us to understand quickly the effect of the various lobe generated secondary flow mechanisms on mixer behavior.

Figure 12 illustrates the effect of turbulence model on the total temperature signatures at the mixer nozzle exit. The turbulence model in the analysis supplies information to the governing flow equations about the nature of the turbulent transport process. The effect of turbulence model on the mixing process was studied using color image techniques.

CONCLUDING REMARKS

Color coding techniques used in the processing of remote sensing imagery have been applied to the fluid dynamic problems associated with modern turbofan mixer nozzles. These computer generated color graphic techniques were found to be particularly useful to (1)

reconstruct the experimental flow field from limited data to give more physical meaning to this information and (2) scan and interpret large volumes of computer generated data from a three dimensional viscous analysis. Color coding of data was found to be an important graphical cue to the comprehension and retention of information because the color code itself can be easily remembered. Color animated movie techniques, when applied to mixer nozzle problems, increased our awareness to the fact that the fluid interaction under study was indeed dynamic, and that important judgements can be reached about the dynamic nature of the process which would otherwise be very difficult.

REFERENCE

1. Kuchar, A. P. and Chamberlin, R., "Scale Model Performance Test Investigation of Exhaust System Mixers for an Energy Efficient Engine (E^3) Propulsion System," AIAA Paper 80-0229, Jan. 1980.

2. Shumpert, P. K. "An Experimental Model Investigation of Turbofan Engine Internal Exhaust Gas Mixer Configurations," AIAA Paper 80-07[illegible]an. 1980.

3. Kozlowski, H. and Kraft, J., "Experimental Evaluation of Exhaust Mixers for an Energy Efficient Engine," AIAA Paper 80-1088, June 1980.

4. Bowditch, D. [illegible]., et al., "Computational Fluid Mechanics of Internal Flow," Aeropropulsion 1979, NASA CP-2092, 1979, pp. 187-230.

5. Povinelli, L. A., Anderson, B. H., and Gerstenmaier, W., "Computation of Three-Dimensional Flow in Turbofan Mixers and Comparison with Experimental Data," AIAA Paper 80-0227, Jan. 1980.

6. Povinelli, L. A., Anderson, B. H., and Gerstenmaier, W. H., "Computation of Three-Dimensional Flow in Turbofan Mixers and Comparison with Experimental Data", Jan. 1980.

7. Anderson, B. H., Povinelli, L. A. and Gerstenmaier, W. H., "Influence of Pressure Driven Secondary Flows on the Behavior of Turbofan Forced Mixers," June 1980.

8. Anderson, B. H., and Povinelli, L. A., "The Effects of Macro Vortex Interactions on the Characteristics of Turbofan Forced Mixer Nozzles," AIAA Paper 81-0274, Jan. 1981.

9. Briley, W. R. and McDonald, H., "Analysis and Computation of Viscous Subsonic Primary and Secondary Flows," Computational Fluid Dynamics Conference, American Institute of Aeronautics and Astronautics, Inc., New York, 1979, Paper AIAA 79-1453, pp. 74-88.

10. Kreskovsky, J. P., Briley, W. R., and McDonald, H., "Development of a Method for Computing Three-Dimensional Subsonic Turbulent Flows in Turbofan Lobe Mixers," 879-300006-F, Scientific Research Associates, Inc., Glastonbury, CT., Nov. 1979.

11. Giamati, C. C.; "Application of Image Processing Techniques to Fluid Flow Data Analysis," Presented at the 11th Annual Computer-Output Microfilm Technology Conference (COMtec), Lincolnshire, IL, Feb. 24-26, 1981.

12. Newman, W. M., and Sproull, R.: "Principles of Interactive Computer Graphics," 2nd ed., McGraw Hill, New York, 1979.

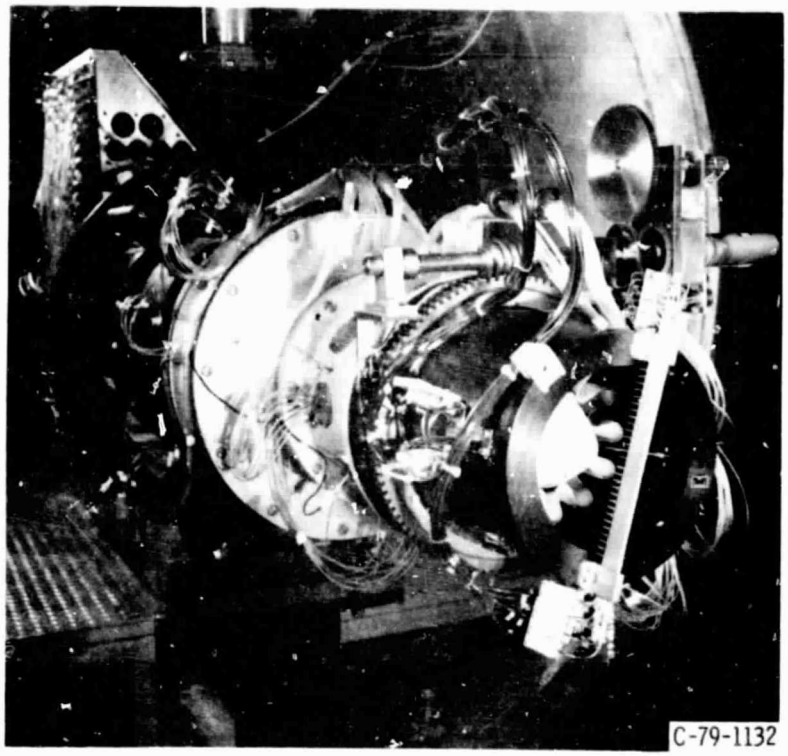


Figure 1. - Experimental mixer nozzle.

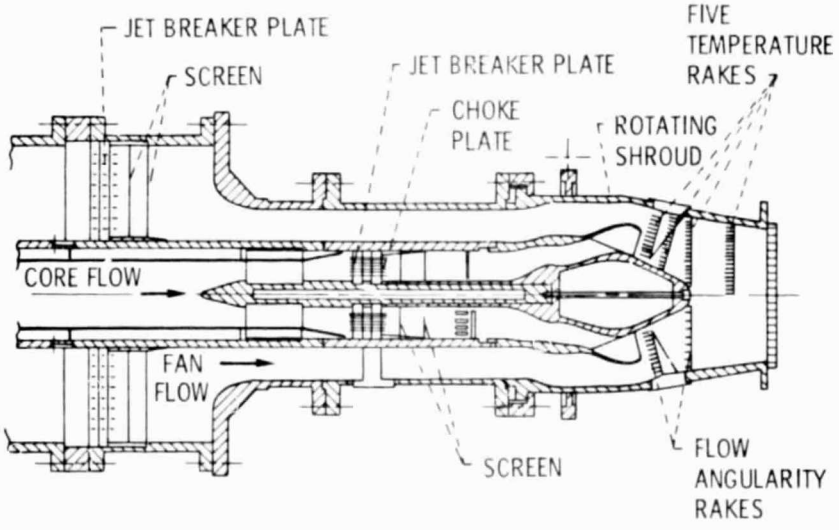


Figure 2. - Mixer nozzle cross-section.

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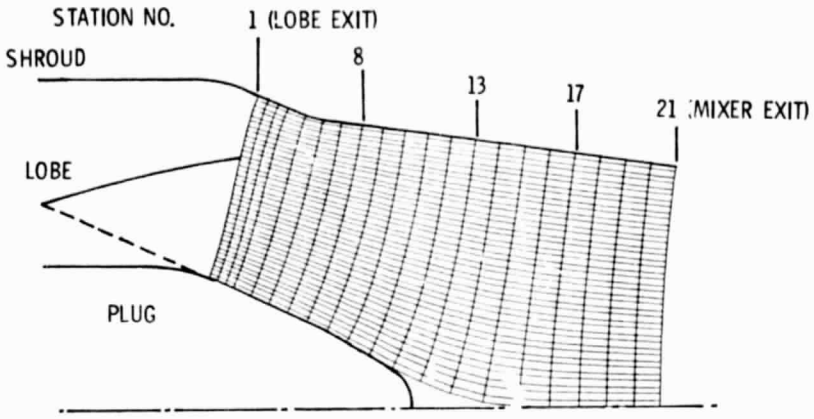


Figure 3. - Mixer nozzle computational mesh.

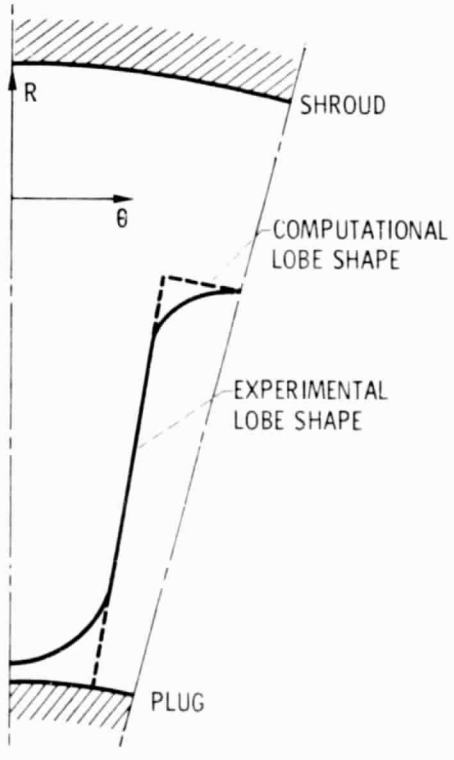
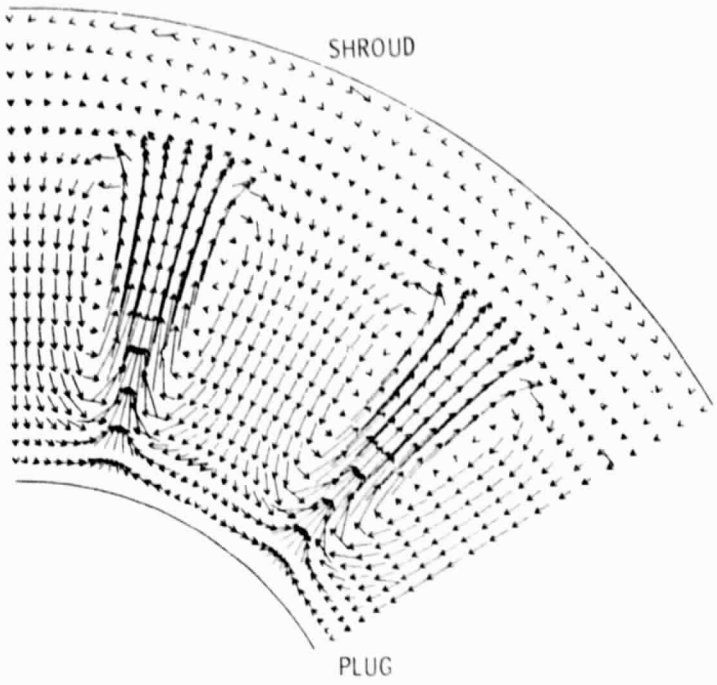
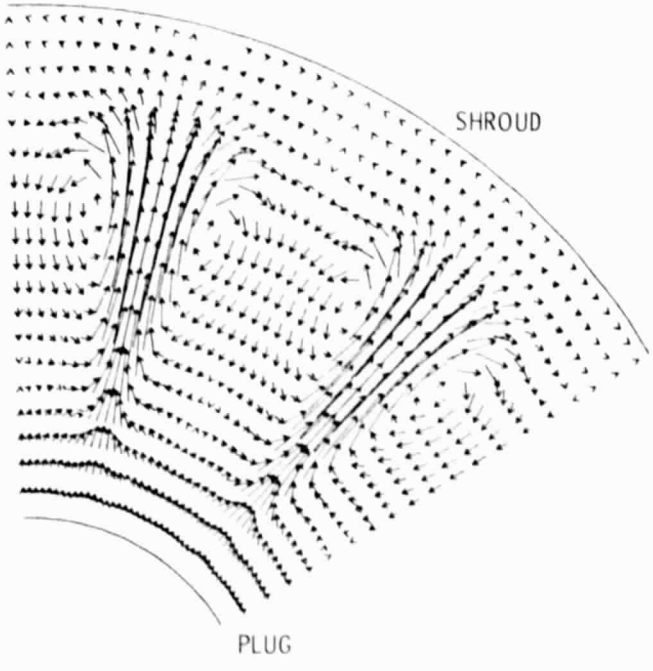


Figure 4. - Transverse computational domain.



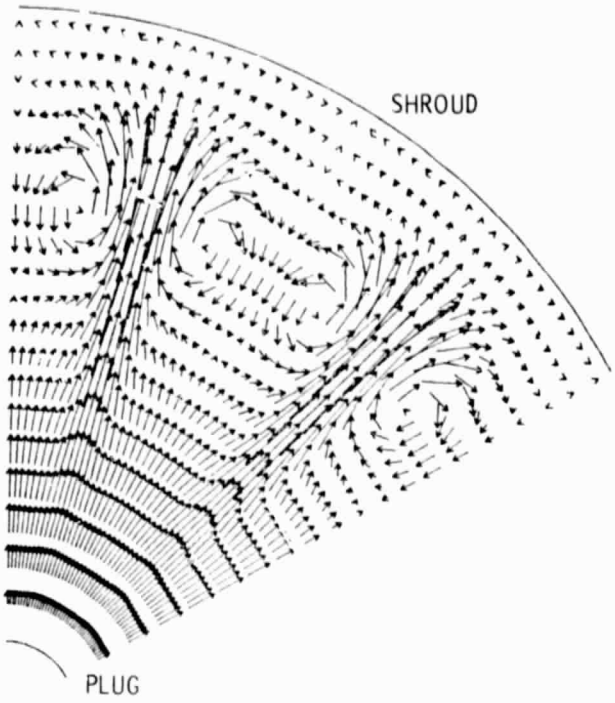
(a) Lobe exit, Station no. 1.

Figure 5. - Computed secondary velocity vectors.



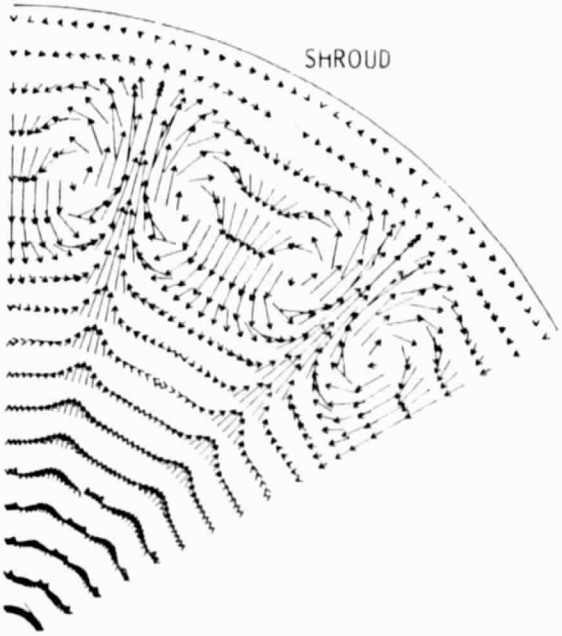
(b) Station no. 8.

Figure 5. - Continued.



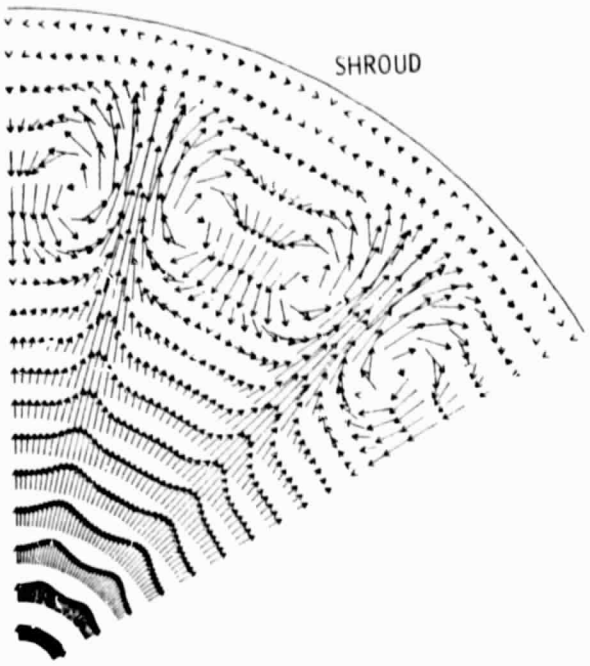
(c) Station no. 13.

Figure 5. - Continued.



(d) Station no. 17.

Figure 5. - Continued.



(e) Mixer exit, Station no. 21.

Figure 5. - Concluded.

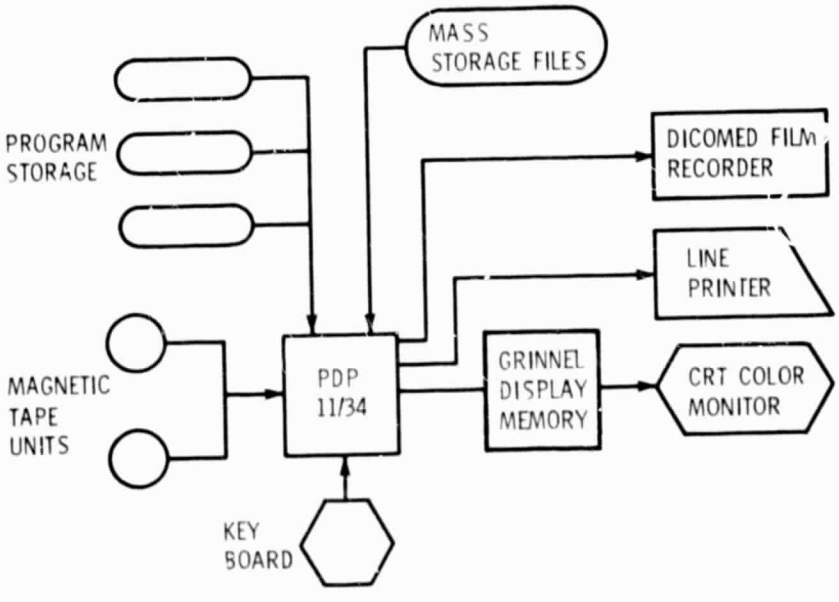


Figure 6. - Lewis image processor.

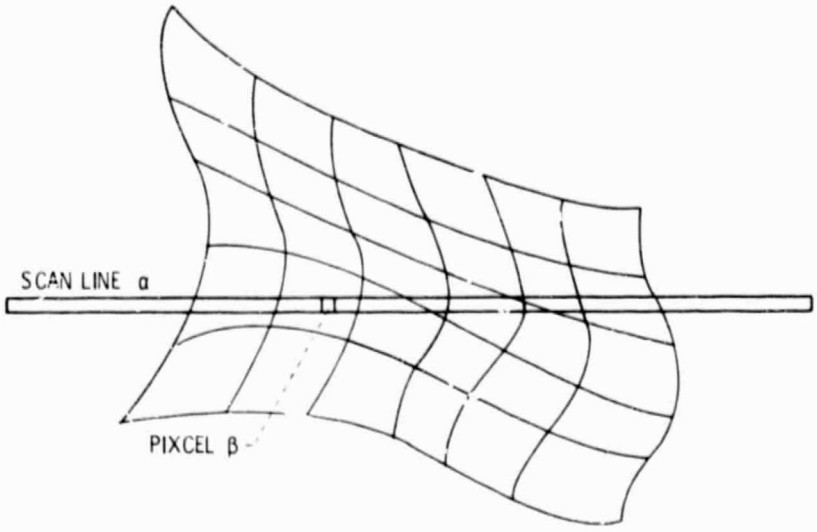
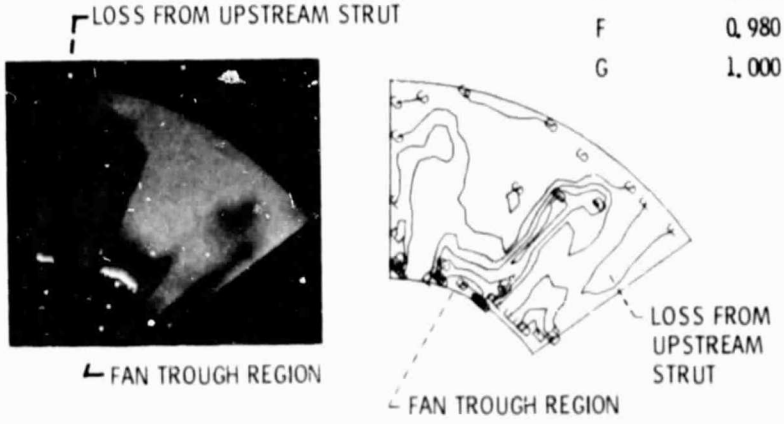


Figure 7. - Interpolation along a scan line on a generalized grid system.

CONTOUR LABEL	CONTOUR VALUE
A	0.880
B	0.900
C	0.920
D	0.940
E	0.960
F	0.980
G	1.000
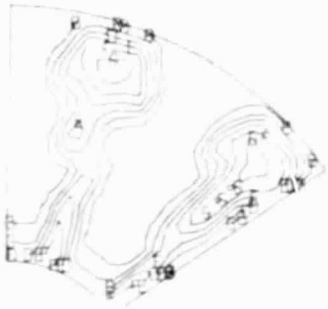


(a) Signature. (b) Contours.

Figure 8. - Comparison between color image signature and standard contour representation for total pressure at lobe exit, Station no. 1.

CONTOUR LABEL	CONTOUR VALUE
A	0.700
B	0.750
C	0.800
D	0.850
E	0.900
F	0.950
G	1.000



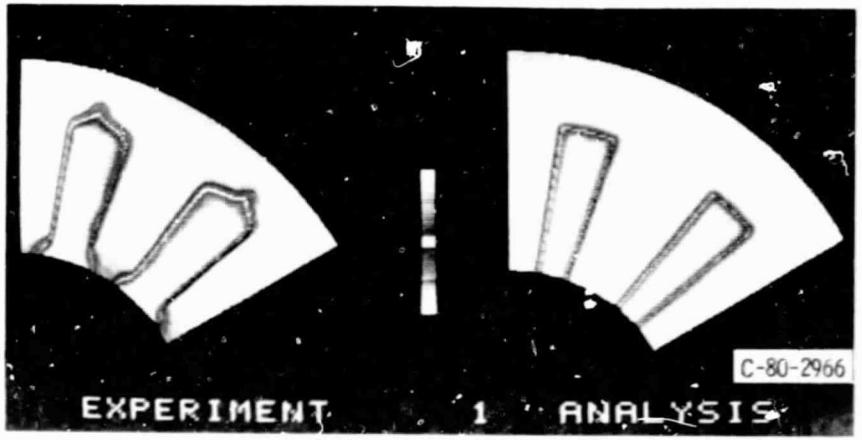
(a) Signature.



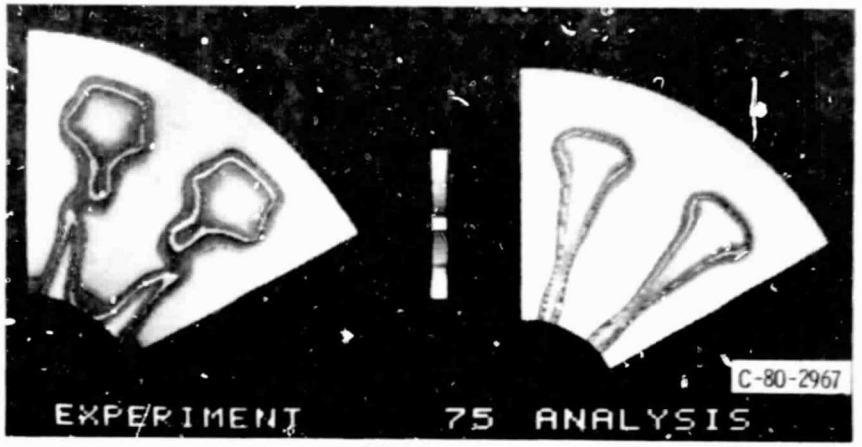
(b) Contours.

Figure 9. - Comparison between color image signature and standard contour representation for total temperature at Station no. 8.

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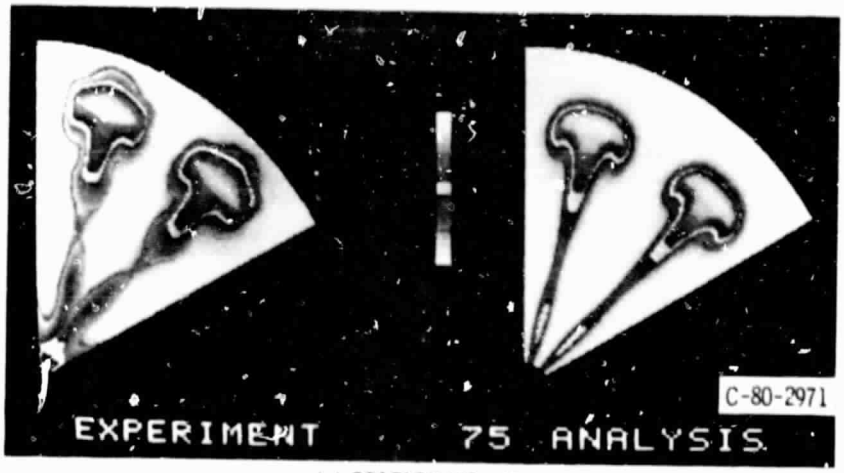


(a) LOBE EXIT, STATION NO. 1.

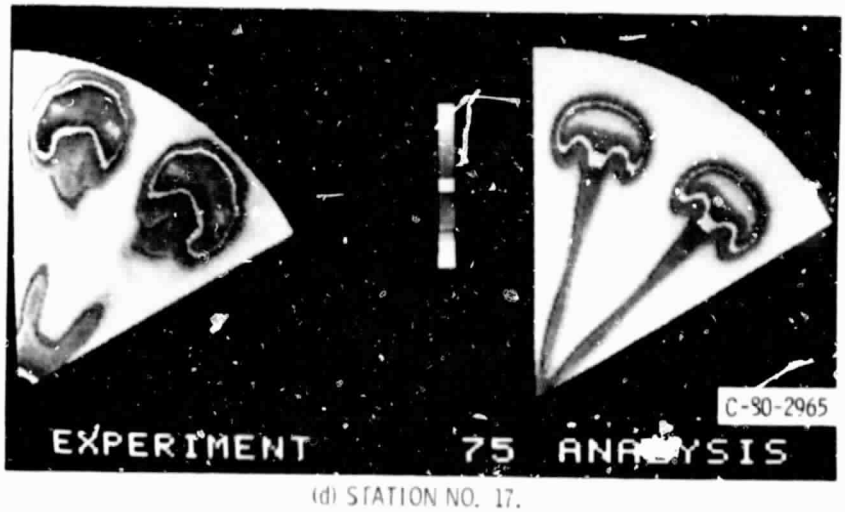


(b) STATION NO. 8.

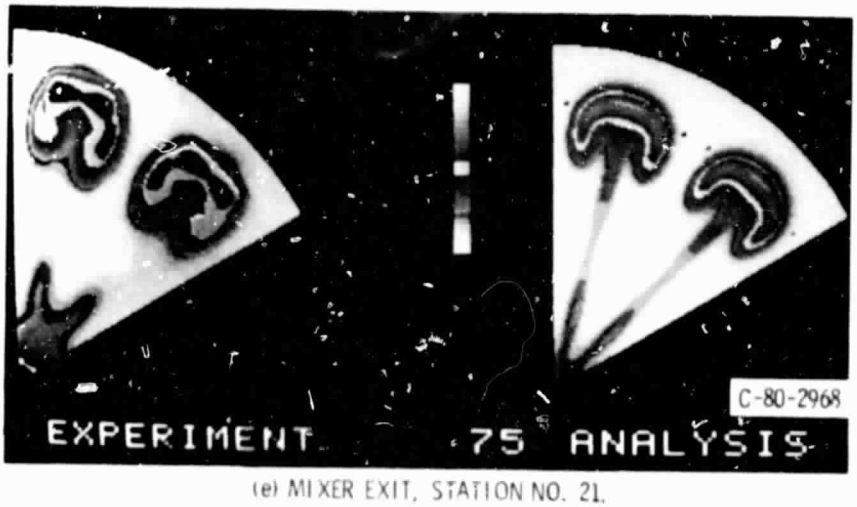
Figure 10. - Comparison between the measured and calculated total temperature signatures.



(c) STATION NO. 13.



(d) STATION NO. 17.



(e) MIXER EXIT, STATION NO. 21.

Figure 10. - Concluded.

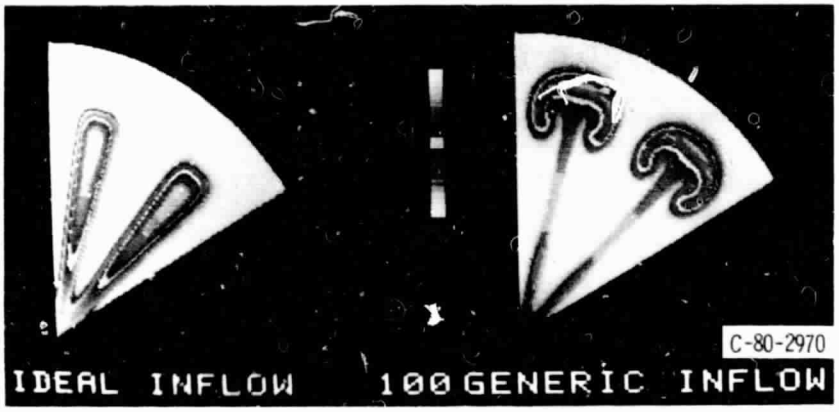


Figure 11. - Effect of inflow condition on the total temperature signatures at station no. 21.

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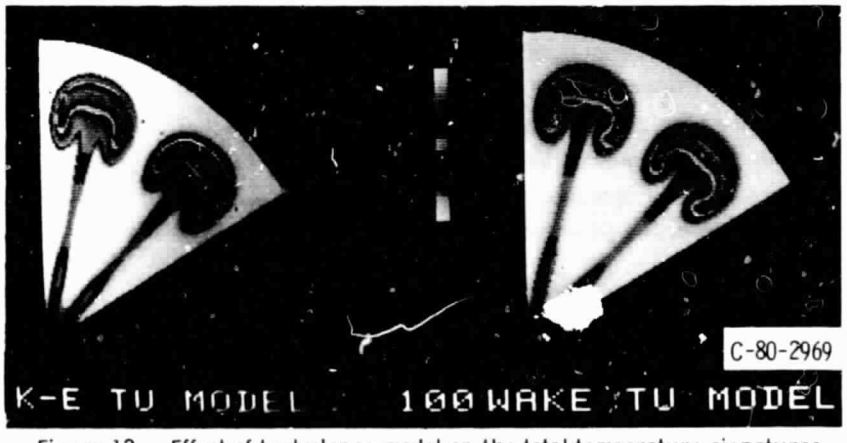


Figure 12. - Effect of turbulence model on the total temperature signatures at station no. 21.